CO_2-BASED DEMAND-CONTROLLED VENTILATION CONTROL STRATEGIES FOR MULTI-ZONE HVAC SYSTEMS

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ABSTRACT

CO_2-based demand-controlled ventilation DCV strategy offers a great opportunity to reduce energy consumption in HVAC systems while providing the required ventilation. However, implementing CO_2-based DCV under ASHRAE 62.1.2004 through 2010 is not simple as it was under previous versions due to the changes in breathing-zone ventilating rate calculations. This paper discusses the difficulties in the CO_2-based DCV and proposes an alternative strategy based on the supply air CO_2 concentration. The proposed strategy offers great benefits in terms of better indoor air control and improved energy efficiency and could be easily implemented for multi-zone HVAC systems. To evaluate the strategy, energy simulations were performed on various USA locations and for a typical two-story office building conditioned by a VAV system. The results show that the cooling saving could be up to 23% by implementing the proposed strategy as compared to the design-occupancy ASHRAE Standard 62.1 2010 procedure.

INTRODUCTION

Over many years, there has been growing awareness of the need to improve the quality of air inside buildings and reduce the associated energy use. Several ventilation control strategies are proposed for HVAC systems (Carpenter 1996, Wang and Jim 1998, Wang and Xu 2002, and Nassif et al 2005, Nassif et al 2007). These methods, which have been discussed in many publications, may or may not satisfy the new requirements of ASHRAE 62.1 2010 (ASHRAE 62.1 2010). The CO_2-based demand-controlled ventilation (DCV) is one of the strategies that could lower energy use by reducing over-ventilation of buildings (Alalawi and Krarti 2002; Taylor 2006, Stanke 2006). When such strategy is applied by detecting the CO_2 concentration in return air as in most case, it may result in poor air quality inside certain zones in a multi-zone building. In addition, most DCV strategies are based on flow rate per person (ASHRAE Standard 62-1989 through 2001) and those may not comply with the new ventilation requirements of ASHRAE 62.1 2004 through 2010. Those versions of Standard prescribes two ventilation rates, one intended to dilute the contaminants generated by occupants and other for building-related sources. Due to these two sources, the required space CO_2 concentration or the indoor-outdoor difference is no longer constant as it was in ASHRAE Standard 62.1 1989 through 2001 (Stanke 2006, Murphy 2005). The required space CO_2 concentration varies with the occupants, making any CO_2-based DCV strategy hard to apply and comply exactly with the recommendations of the Standard 62.1 2010. Although the Standard permits applying CO_2-based DCV strategy or any dynamic ventilation reset strategy, a considerable challenge with multi-zone HVAC systems arises. In addition, as it is costly and difficult (but not impossible) to estimate accurately the actual occupants in each space, the Standard procedure is mostly based on a design occupancy profile, leading to over-ventilate the spaces yielding less than design occupants and consequently waste of energy. As a result of these challenges, an alternative CO_2-based DCV strategy is proposed to maintain the CO_2 concentration in supply air a low enough to meet the ventilation requirements in all zones and improve energy efficiency. The paper also provides insight into the performance of a typical VAV system under different operating and ventilation requirement conditions and discusses the difficulties in CO_2-based DCV strategy and potential solutions.

ZONE VENTILATION CALCULATION

The ventilation rate procedure in ASHRAE Standard 62.1-2010 has specific calculations for multi-zone systems. The Standard prescribes two ventilation rates, one intended to dilute the contaminants generated by occupants (R_p) and other for building-related sources (R_a). The required minimum breathing zone outdoor air rate V_{bz} as a function of the number of zone occupants P_z and the zone floor area A_z is given:

$$V_{bz} = R_p \times P_z + R_a \times A_z \tag{1}$$

The R_p and R_a are determined from the table in Standard 62.1 based on the occupancy type. The breathing zone outdoor air rate needs to be adjusted to account for the supply diffuser, and return grill location, supply air temperature, and other factors by including the zone air distribution effectiveness E_z:

$$V_{oz} = \frac{V_{bz}}{E_z} \tag{2}$$

The outdoor air fraction in discharge air supplied to each zone Z_{dz}:

$$Z_{dz} = \frac{V_{oz}}{V_{dz}} \tag{3}$$

The outdoor air rate in all breathing zones V_{ou} (uncorrected outdoor air intake flow):

$$\begin{aligned} V_{ou} &= \sum R_p \times P_z + \sum R_a \times A_z \\ &= R_p \times P_b + \sum R_a \times A_z \end{aligned} \tag{4}$$

The total number of occupants P_b (occupants in whole building) is equal to the sum of the occupants in each zone P_z. The uncorrected outdoor air fraction X_s to system supply air V_{ps}:

$$X_s = \frac{V_{ou}}{V_{ps}} \tag{5}$$

The efficiency for each zone E_{vz}:

$$E_{vz} = 1 + X_s - Z_{dz} \tag{6}$$

The system efficiency E_v

$$E_v = min(E_{vz}) \tag{7}$$

The minimum required system outdoor air flow V_{ot} and corrected outdoor air fraction X_{sc}:

$$V_{ot} = \frac{V_{ou}}{E_v} \tag{8}$$

$$X_{sc} = \frac{V_{ot}}{V_{ps}} \tag{9}$$

CO_2 CONCENTRATION CALCULATIONS

This section is intended to develop the CO_2 concentration equations required for the model simulation and for the proposed strategy discussed in the next section. The air supplied to the space is assumed to be well mixed and the efficiency E_z=1. ASHRAE Standard 62.1 provides the mass balance equation to predict the difference between indoor CO_2 concentration (C_z) and outdoor CO_2 concentration (C_o) at steady-state conditions:

$$V_{oz} = \frac{N_z}{(C_z - C_o)} \tag{10}$$

The N_z is the CO_2 generation rate and it is a function of people number (N_z=C×P_z); where the C is a constant value related to the occupancy activities, level, diet, health, and etc. In our example below, we will consider C = 0.0049 L/s of CO_2 per person (0.0105 cfm of CO_2 per person). The space CO_2 concentration C_z is given:

$$C_z = C_o + \frac{N_z}{V_{oz}} \tag{11}$$

If the recommended ventilation rate V_{oz} is supplied to the space (Equation 1, E_z=1), the resulted space CO_2 concentration C_z is

$$C_z = C_o + \frac{C \times P_z}{R_p \times P_z + R_a \times A_z} \tag{12}$$

To ensure that the ventilation rate recommended by Equation 1 is supplied to the space, the measured space CO_2 concentration should be equal to (or lower than) the value determined by Equation 12. In ASHRAE Standard 62.1 1989 through 2001, the term (R_a×A_z) does not exist and the term P_z is cancelled out, leading to have a constant required value of C_z or (C_z-C_o) that equals C/R_p. In ASHRAE Standard 62.1 2004 through 2010, the existence of the term (R_a×A_z) makes the C_z or (C_z-C_o) no longer be constant and it is the major source of the challenge for any CO_2-based DCV.

Using the CO_2 concentration in supply air C_s, the steady state mass balance (equation 10) becomes:

$$V_{dz} = \frac{N_z}{(C_z - C_s)} \tag{13}$$

The CO_2 concentration in supply air C_s is given by Equations 11, 12, and 13 as a follow:

$$C_s = C_z - \frac{N_z}{V_{dz}} = C_o + N_z\left(\frac{1}{V_{oz}} - \frac{1}{V_{dz}}\right) \tag{14}$$

Equation 14 represent the required value of the supply air CO_2 concentration for each space to maintain the space concentration at any chosen value of C_z either required by the Standard or any arbitrary value. As will be discussed in the next section for the proposed strategy, the calculation of the supply air CO_2 concentration is repeated for each zone and the minimum value should be selected to ensure there is no zone having a CO_2 concentration value higher than the required value specified by Equation 12.

For the simulation purpose, the CO_2 concentration balance equation can be used to map the relation between the CO_2 concentrations and outdoor flow rate (*(note $\Delta C=C_r-C_s$)*:

$$V_{ot} = V_{ps} \times \frac{(C_r - C_s)}{(C_r - C_o)} = V_{ps} \times \frac{\Delta C}{(C_r - C_o)} \quad (15)$$

SUPPLY AIR CO_2 CONCENTRATION DCV STRATEGY (SADCV)

The CO_2 -based demand-controlled ventilation is specifically allowed by ASHRAE Standard 62.1. In one zone application, the CO_2-based DCV may be simple and straightforward but this would not be as simple when dealing with multi-space systems. With ASHRAE Standard 62.1 2004 through 2010, due to the occupancy and building related sources, the required CO_2 concentration in space (Equation 12) varies with the occupancy and the CO_2-based DCV seems to be difficult to apply in practice. Here, we are proposing a control ventilation strategy based on supply air CO_2 concentration (SADCV) for multi-space systems in effort to meet the recommendation of the Standard 62.1 2010. Again, Equation 14 represents the supply air CO_2 concentration required to maintain the space CO_2 concentration at any value specified by the Standard. The calculation of the supply air CO_2 concentration is repeated for each zone i and the minimum value is selected:

$$C_s = min\{C_{si}\} = min\left\{C_{zi} - \frac{N_{zi}}{V_{dzi}}\right\} = min\left\{C_o + N_{zi}\left(\frac{1}{V_{ozi}} - \frac{1}{V_{dzi}}\right)\right\} (16)$$

In practice, it is hard to estimate the actual number of occupants in each zone to find V_{ozi} and N_{zi} unless there is a CO_2 sensor located in each zone but this will very costly and also can not ensure a perfect estimation. Thus, the design number of occupants is considered to maintain the supply air CO_2 concentration low enough to dilute CO_2 generated by full occupancy. The N_{zi} and V_{ozi} in Equation 16 are always found based on "*the design number of occupants*". In that case, the supply C_s is only a function of the actual values of zone airflow rates V_{dzi}, which are available in most of HVAC systems with direct digital control. If the actual occupancy is less than design, a lower value of return air CO_2 concentration and consequently a lower amount of outdoor air introduced to maintain a given supply air CO_2 concentration.

To implement the SADCV strategy, a local PI/or PID control loop along with a CO_2 sensor located in the supply air duct should be installed. As shown in Figure 1, the controller output is determined by comparing the measured CO_2 concentration in the supply air with its set point to modulate the outdoor air dampers. The supply air CO_2 concentration set point is dynamically reset by Equation 17 on a proper time interval basis (e.g. each 5 minute) using only the zone airflow rate readings.

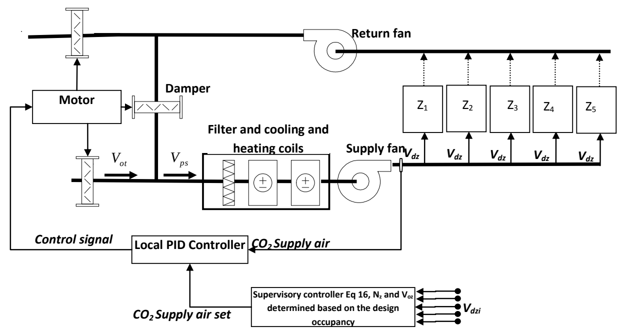

Figure 1. Schematic of Supply air CO_2 concentration control strategy with a typical VAV system

PERFORMANCE ANALYSIS

A variable air volume (VAV) system supplying conditioned air to similar five zones is selected for performance analysis. The zones are assumed to be lecture classes each with design population of 60, a floor area of 93 m^2 (1000 ft^2), and flow rate of 944 L/s (2000 cfm). To simplify our discussions, we consider the following assumptions: the total design supply air is 4720 L/s (10,000 cfm) as a sum of design zone airflow rates (no diversity factor is applied), the zone air-distribution effectiveness (Ez) is selected to be equal 1.0, the CO_2 generation rate N of the occupants is equal to 0.0049 L/s (0.0105 cfm) of CO_2 per person, the outdoor air CO_2 concentration is 350 PPM, the R_p =2.3 L/s/person and R_a=0.028 L/s/m^2 (R_p =5 cfm/person and R_a=0.06 cfm/ft^2) are used in minimum breathing zone outdoor air equation (Equation. 1). For evaluation purpose, the supply air flow rate in only one zone, as a critical zone, will be varied from a minimum value to the design one while the flow rates in other zones are kept constant at fixed design values. The minimum value of the air flow rate is limited to be always higher than the required ventilation flow rate.

To evaluate the proposed strategy SADCV, a performance comparison is made between the

SADCV and the calculations according to ASHRAE Standard 62.1 ventilation rate, represented by Equation 1 through Equation 9. Three scenarios are considered. The first one is when the actual number of people in each zone can be identified (e.g. exact occupancy schedule, occupancy or CO_2 sensors, etc), the Standard ventilation procedure can be dynamically applied by using those actual values. Although that scenario cannot be achieved easily in practice for multi-zone systems without high cost associated, the strategy is presented here for a comparison purpose and it is referred to as a strategy S_3. The calculations in the strategy S_3 is done by using the actual values of P_z and P_b in Equations 1 and 4. The second scenario is that the number of people in whole building level can be identified but not in each space. This scenario is also used for a comparison purpose and refer here as a strategy S_2 and may not be easily achieved in practice. The third and most possible scenario is that when the number of people varies randomly and there is no accurate information available on actual occupants and then the design profile has to be used in Equations 1 and 4 to calculate the ventilation flow rate (in our example, the design values P_z =60 and P_b= 300). This scenario is referred as a strategy S_1. For all these scenarios including the proposed strategy, the calculations will be performed with varying the supply air in only one of the five zones as a critical zone and keeping the others at constant design values (non-critical zones). The performance comparison will be in term of zone and system ventilation flow rates and CO_2 air concentrations. The zone and system ventilation flow rates are calculated by Equations 1-9. The difference between supply and return CO_2 concentrations (ΔC) is equal to that generated by the actual number of people. When the outdoor airflow rate is determined by the Standard procedure (such as in strategies S_1, S_2, and S_3), the return air CO_2 concentration is found through CO_2 balance equation (Equation 16) and consequently the supply air CO_2 concentration. However, when the supply air CO_2 concentration is determined by SADCV, the outdoor air flow rate is also obtained by Equation 16. The return CO_2 concentration is equal to the supply CO_2 concentration determined by SADCV plus the CO_2 concentration generated by the actual occupants. For all strategies, the CO_2 concentration in each space can be found based on the actual occupancy and flow rate (Equation 13).

The discussions will be limited to two occupancy conditions when the number of people in the critical zone P_z is 60 and P_z is 30. In both conditions, the occupancy in each of non-critical zones is assumed to be at 30 and the whole building occupancy P_b is then 180 and 150 respectively. Table 1 shows the results for one particular operating condition when the supply air is 472 L/s (1000 cfm) (50% of design value) in the critical zone z_1 and 944 L/s (2000 cfm) in non-critical zones z_2-z_5 but for two occupancy schemes P_z=60 and P_z=30 represented as (A) and (B), respectively. Let us consider first the condition “A” when the number of people in the critical zone (Z_1) is equal to 60 (P_{z1}=60) and it is equal to 30 ($P_{z2\text{-}Z5}$=30) in other zones (z_2 to z_5) so that the building occupancy is 180 (P_b=180). The difference between supply and return air CO_2 concentration (ΔC) is equal to 210 PPM, generated by the total number of occupants (P_b=180) with the supply air V_{ps} of 4248 L/s (9000 cfm) (i.e. N=0.0105 cfm of CO_2 /person, then $\Delta C=0.0105\times10^6\times P_b/V_{ps}=210$ PPM). The strategy SADCV determines the supply air CO_2 concentration of 1470 PPM by Equation 16, the return CO_2 concentration is then 1680 PPM (add ΔC=210 PPM) , and the outdoor air flow rate is 670.7 L/s (1421 cfm) calculated by the CO_2 balance equation (Equation 16). For the strategies S_1, S_2, and S_3 the outdoor airflow is determined through ASHRAE Standard 62.1 recommended procedure (Equation 1 through 9), considering design or actual occupancy. Using ΔC=210 PPM in the Equation 16, the return CO_2 concentration is found (i.e. C_r=1568 PPM for S_2 and S_3), and then supply CO_2 concentration as well (i.e. C_s=1358 PPM for S_2 and S_3). Based on the actual airflow rate and occupancy, the CO_2 concentrations in the critical zone Z_1 (C_{z1}) and non-critical zones $Z_{2\text{-}5}$ ($C_{z2\text{-}z5}$) are determined as shown in Table 1.

From Equation 10 or 12, the required CO_2 concentration in the critical zone is 2100 PPM and the standard based on the actual occupancy (strategy S_3) produces 1988 PPM, not 2100 PPM. The SADCV produces exactly 2100 PPM and provides less outdoor air than the standard. This is because that under this particular condition, the SADCV uses the air mixture that contains a portion of the fresh air related to the building source and the strategy S_3 does not. The equation 10 or 12 works well for one zone application or multi-space when the occupancy related source is solely considered as it was in old versions of the standard. Using part of air related to the building source may be debatable and this issue will not be discussed here. Fortunately, in many cases, the occupancy in the critical zone does not necessary to be under design occupancy and the actual CO_2 concentration could be less than that obtained by SADCV (i.e. 2100 PPM).

Table 1. Ventilation and CO_2 concentration results when the supply air is 472 L/s in the critical

zone z_1 and 944 L/s in non-critical zones z_2-z_5 and for two occupancy schemes P_z=60 and P_z=30 represented by (A) and (B), respectively

	Outdoor air L/s	*CO_2 Concentration in Z_1 PPM*	*CO_2 Concentration in Z_2-Z_5 PPM*	*CO_2 Concentration in return air PPM*	*CO_2 Concentration in supply air PPM*
	A				
S1	1011.5	1652	1180	1232	1022
S2	732.5	1988	1516	1568	1358
S3	732.5	1988	1516	1568	1358
SADCV	670.7	2100	1628	1680	1470
	B				
S1	1011.5	1225	1068	1085	910
S2	655.1	1625	1468	1485	1310
S3	546.6	1850	1693	1710	1535
SADCV	574.0	1785	1628	1645	1470

Airflow rate: V_{dz1}=472 L/s (1000 cfm), V_{sz2-z5}=944 L/s (2000 cfm), V_{ps}=4248 L/s (9000 cfm)
A: P_{z1}=60, P_{z2-z5}=30, P_b=180, required C_{z1}=2100 PPM, C_{z2-z5}=1850 PPM based on Equation 12
B: P_{z1}=30, P_{z2-z5}=30, P_b=150, required C_{z1}= C_{z2-z5}=1850 PPM based on Equation 12

Let us look at "B" when the critical zone as well as other zones (all five zones) have the same occupants (P_z=30). The SADCV sets the supply air CO_2 concentration at a value of 1470 PPM the same as for "A" as it is always based on critical zone design occupancy P_{z1}=60. Less than design occupancy in the critical zone causes lower CO_2 concentration in return air (1645 PPM vs. 1680 PPM) and outside air (574 L/s vs. 670.7 L/s) to maintain the same supply air CO_2 concentration of 1470 PPM. It also produces CO_2 concentration in the critical zone less than that for the standard (1785 PPM vs. 1850 PPM) and outdoor air higher than that for the standard (574 L/s vs. 546.6 L/s)

The calculations shown in Table 1 are repeated for various flow rates in the critical zones as shown Figures 2-4. When the occupancy in the critical zone is still at a design value and the occupancy in other zones drops to half, the strategies S_2 and S_3 perform similarly as the actual critical zone occupancy is the same as the design one (see left sides of Figures 2-4). The SADCV provides exactly CO_2 concentration as determined by Equation 10 or 12 (2100 PPM), which is slightly higher than that determined by the Standard ventilation rate procedure (Strategy S_3). The SADCV provide less outdoor air than the standard due to the air mixture from various spaces including the building-related ventilation portion.

Additional challenge with SADCV is that as the supply CO_2 concentration is based on design occupants in the critical zone, the strategy tends to maintain the space CO_2 concentration required by the Standard at full occupants. If the number of people is less than design P_z=30 (right sides in Figures 3-4), both actual and required CO_2 concentration would be less than those design values but not necessary be equal. The required CO_2 concentration by the standard (S_3) is 1850 PPM and actual value by SADCV varies with the critical zone flow rates and close to the standard value but not exactly equal. It is clear that the SADCV performs relatively close to that for the strategy S_3 but does not exactly match.

To avoid the possibility of using any part of building-related ventilation and ensure that the outdoor air supplied by SADCV is higher slightly than the standard, the CO_2 concentration set point can intently set at lower than calculated by equation 16. As shown in equation 15, a decrease of supply air CO_2 concentration will increase the outdoor air fraction. Using the least possible supply air (e.g. 50% of design condition=5000 cfm= 2360 L/s), the fraction of the outdoor air related to the building source (Ra*∑A) can be estimated (in our example Ra*∑A=300 cfm=142 L/s, then outdoor air fraction is 6%) and the correction is then 100 PPM based on the design space CO_2 concentration 2100 PPM and the outdoor air CO_2 concentration 350 PPM. A dynamic correction factor can be also considered by performing sample measurements for the return, supply, and outdoor concentrations for various operating conditions. Figure 4 shows the outdoor air flow rate and associated CO_2 concentration in the critical zone when a correction factor of 100 PPM is subtracted from the supply CO_2 concentration set point. The outdoor air flow rate supplied by SADCV becomes very close to that for the strategy S_3 and an amount of air that equals to building-related ventilation rate is avoided to be recirculated into the supply air. The accuracy of the CO_2 concentration sensor is critical in the proposed SADCV strategy and any CO_2 based strategies. Under this condition, the error within ±50 PPM produces a variation of the outdoor air fraction within ±3%. Sensor calibration and field measurements are recommended to verify the accurate operations and achieve the full benefits of the strategy.

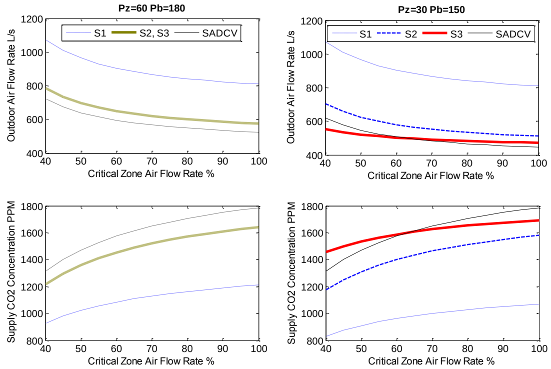

Figure 2. Outdoor air flow rates and supply air CO_2 concentration for two occupancy schemes Pz=60 and Pz=30

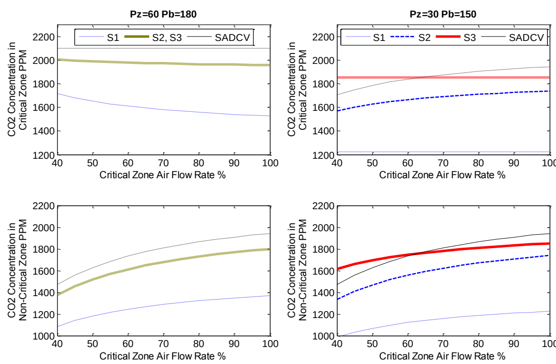

Figure 3. *CO_2 concentration in the critical and non-critical zones* for two occupancy schemes Pz=60 and Pz=30

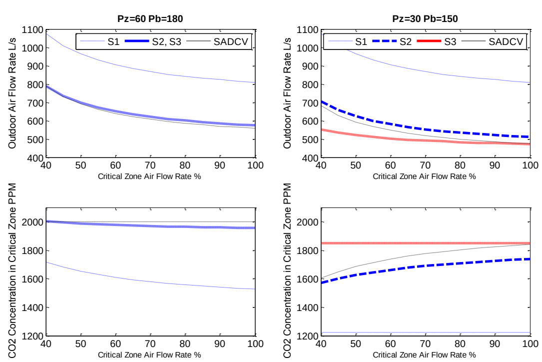

Figure 4. *Outdoor air flow rate and CO_2 concentration in the critical zone when a correction factor of 100 PPM is subtracted from the supply CO_2 concentration set point*

ENERGY SIMULATION

For multi-zone systems, it is difficult to identify the actual occupancy in each individual zone without associated high and unjustified cost and thus, the ventilation calculations recommended by ASHRAE Standard 62.1 2010 is mostly done based on the design occupancy profile but with the actual zone airflow rates if available. The inexpensive and easy-to apply SADCV strategy is recommended in this paper as an alternative either of using the Standard calculations based on the design occupancy or installing occupancy sensors in each zone to identify the actual number of occupancy. This section will be limited to estimate the energy cooling saving obtained by applying the SADCV against ASHRAE Standard 62.1 ventilation design-occupancy and actual-flow procedure. We will not deal with the installation cost and the cost saving by applying this strategy as compared to other techniques using occupancy sensors or CO_2 sensors in each space.

A two-story office building is used for the simulations. It is a rectangle footprint shape with floor area of 2323 m^2 (25,000 ft^2). There are twelve zones, six zones at each floor (two cores, east, west, north, and south). The core area combines 26% general office and 26% conference room and the perimeter area combines of 41.2% private/executive office and 6.8% others. A total number of people are 422. A standard design occupancy profile is used during the occupied period from 8 AM to 5 PM.

The energy simulation software eQuest is used to generate the hourly space loads and a separate VAV model based ASHRAE HVAC 2 Toolkit (Brandemuel et al 1993, Nassif et al 2004) is used to determine the cooling load on coils. The total cooling energy use is found based on the DOE-2 chiller model (DOE 1980). A linear interpolation is used to find the space load on a smaller interval. The simulation runs for various locations covering most of USA climate zones. If the actual occupancy follows exactly the design occupancy profile, the SADCV and design-occupancy Standard 62.1 procedure will provide the same result and there is no real benefit of using the SADCV or any DCV strategies. However, in real application, the actual occupancy may be less than maximum design occupancy. Let us consider two different conditions when the actual occupancy profiles are 75% and 50% of the design occupancy profile.

Figure 5 shows the results obtained for five work days, from August 29 to September 2 and using typical weather conditions. The upper left side shows the flow rates in the zones located only in the ground level G. The calculations for the proposed strategy and Standard ventilation procedure are based on actual zone airflow rates in the ground and upper levels. The upper right side shows the supply CO_2 concentration set points determined by the SADCV strategy and the resulted return air CO_2 concentration under different occupancy profiles (100%, 75%, and 50% of design occupancy). The SADCV determines the supply CO_2 concentration set points repeatedly every five minutes, based on actual airflow rates but always based on design occupancy in zones. This is why the supply CO_2 set point does not vary with the actual number of people (100%, 75%, or 50%). However, when the actual occupancy is less than design (as in 50% or 75%), the return CO_2 concentration and consequently the outdoor airflow become less than the design values (see lower left side in Figure 5). The SADCV is able to reduce the amount of outdoor air as a function of the actual occupancy and thereby reducing heating and cooling energy loads as shown in the lower right side (only for the cooling load). The whole year cooling energy consumptions are also determined with those three options of occupancy profiles (100%, 75%, and 50%) for various locations as shown in Figure 6. When the actual occupancy profile is 50% of design one, the saving in cooling energy could be in range of 15-23% if the SADCV is implemented instead of using the design-occupancy Standard 62.1 2010 procedure (i.e. 100% profile). The saving will be obviously lower as the actual occupancy is getting closer to the design value. The maximum saving is obtained in locations with hot climate and the area where the free cooling is not widely used such as in Orlando. Less saving is obtained in San Francisco and New York due to elevated number of hours when the economizer is activated and fresh air is mostly brought for the free cooling purpose

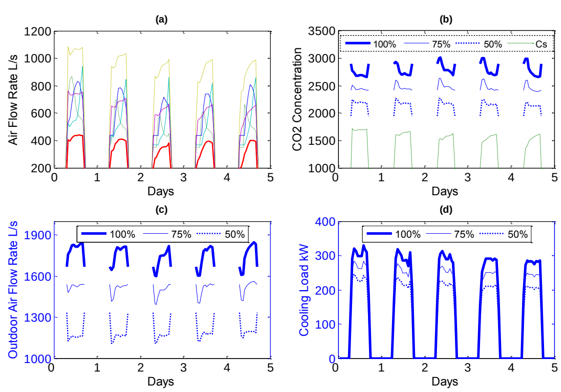

Figure 5. *The results for five work days, from August 29 to September 2, a) airflow rates in zones located in ground level G, b) CO_2 concentration in supply and return air, (c) outdoor airflow rate, and (d) cooling loads on coils*

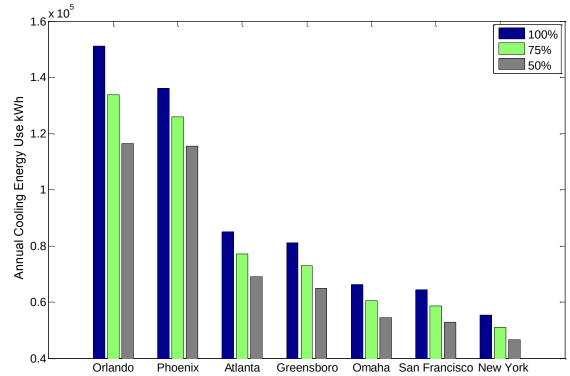

Figure 6. *Annual cooling energy consumption with three options of occupancy profiles (100%, 75%, and 50%)*

SUMMARY AND CONCLUSION

The multi-zone ventilation rate ASHRAE Standard 62.1 procedure includes the zone occupancy number and air flow rate in the calculations. In practice, it is hard to estimate accurately the actual number of occupants in each zone unless there is a CO_2 or occupancy sensor located in each zone but this will be very costly and may not ensure a perfect estimation. Thus, the Standard procedure is mostly based on a design occupancy profile but with actual airflow rate if available. The design-occupancy procedure results in over ventilating the spaces having less than design occupants and consequently waste of energy. Alternately, ASHRAE Standard 62.1 permits applying CO_2-based DCV strategy or any dynamic ventilation reset strategy. However, due to the changes in zone ventilation rate calculations, implementing CO_2-based DCV is not simple and straightforward as it was under old versions. As required by the standard 62.1 2010, two building and occupancy ventilation rates are required and this results in varying the required space CO_2 concentration with the occupancy number. With the old versions of the Standard, a CO_2 concentration reading from a sensor located directly in space or return duct is usually used a signal to control the amount of outdoor air and then maintain the CO_2 concentration at the required value that is always fixed. In other hand, with the new version of the Standard, It is hard to achieve this control approach as the required value of CO_2 concentration varies with the occupancy number, creating a more challenge and difficulty to apply the CO_2-based DCV in practice. As a result of these challenges, an alternative CO_2-based DCV strategy is proposed to maintain the CO_2 concentration in supply air a low enough to meet the ventilation requirements in all zones and improve energy efficiency. This strategy requires implementing control algorithms that monitor the CO_2 concentration in the supply air duct and adjust the outdoor air damper accordingly. Thus, this strategy does not involve significant initial or operating cost and is relatively easy to apply in most multi-zone HVAC systems equipped with direct digital control system. A local PI/or PID control loop along with a CO_2 sensor located in the supply air duct need to be installed. The controller output is determined by comparing the measured CO_2 concentration in the supply air with its set point to modulate the outdoor air dampers. The supply air CO_2 concentration set point is dynamically reset based on actual zone airflow rates and design occupancy on a proper time interval basis.

As it is hard to estimate the actual number of occupants in each zone, the proposed strategy determines the supply CO_2 concentration set point based on the design occupancy. Higher “unused” ventilation air from over-ventilated spaces having less than design occupancy produces lower return air CO_2 concentration and consequently introduces less amount of fresh air to maintain a specific supply air CO_2 set point. The required value of CO_2 concentration varies with the occupants and the maximum value is attained at design occupants. As the supply CO_2 concentration is based on design occupants, the strategy tends to maintain the space CO_2 concentration required at full occupancy. If the number of people is less than design, both actual and required CO_2 concentration would be less than the design values but not necessary similar. Other issue with the proposed strategy and with any CO_2-based DCV strategy is the possibility of recirculating a portion of the building-related ventilation as the return air contains a mixture of both occupancy and building ventilation rates. To avoid this, the CO_2 concentration set point can intently set at lower value. The performance of the SADCV is simulated and compared with the ASHRAE Standard 62.1 ventilation design-occupancy and actual-flow procedure. Energy simulations were performed on various USA locations and for a typical two-story office building with a VAV system. The cooling saving could be up to 25% varied with the locations and occupancy changes. The saving will be lower as the actual occupancy is getting closer to the design value. The maximum saving is obtained in locations with hot climate and the area where the free cooling is not widely used such as in Orlando. Other advantage of the CO_2 concentrating set point is the possibility of optimal coupling between supply CO_2 and temperature control, and potential optimization of the whole system controller set points.

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